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LIGHTWEIGHT FLEXIBLE COMPOSITE TENT MATERIALS

FINAL REPORT

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The program investigated the theory that flexible composite materials can be engineered to provide the physical properties desirable for tent materials, particularly at reduced weights relative to currently available materials. The technology for combining materials into high performance composites is uncommon in the textile industry as a whole, but is commonly practiced by manufacturers specializing in high strength-to-weight ratio materials for applications such as sailcloth and aerospace insulation systems. High strength lightweight composite materials were developed which provide tailored physical properties for use as tent materials. These systems can be produced with commercially-available, reasonably low cost base materials which can be fabricated using existing manufacturing processes. A variety of materials and constructions were shown to meet a majority of the property requirements for the Five-Soldier Crew Tent. Future development of these lightweight constructions should focus on identifying flexible coating systems to improve the hand and durability properties of these continuous film composites.

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INTRODUCTION

Tent materials for the Five Soldier Crew Tent (FSCT) must be strong and lightweight. They must exhibit long term durability in outdoor environments under a wide variety of weather extremes. They must possess fire and water resistance and demonstrate strength retention under repeated use conditions in these extreme environments.

The present material of construction for the FSCT consists of a lightweight polyester duck fabric with a pigmented PVC coating. This system has two major limitations. First, in order to minimize weight, a low denier polyester fabric is used. This limits the ultimate tear strength of the material. Second, the vinyl impregnation, although heavily pigmented, exhibits poor weatherability, resulting in degradation and water leakage even after short term weather exposure.

This project investigates the theory that a flexible composite material can be engineered to provide the physical properties desirable for tent materials, particularly at reduced weights relative to currently available materials. The composite might consist of a base film or nonwoven substrate for strength, durability, and weatherability; fiber reinforcement for additional tear strength in use and during fabrication; and a protective coating for fire resistance, water resistance, ultraviolet resistance and overall durability and toughness. A further consideration is that these composite systems materials are commercially available, and can be fabricated by sewing, taping, heat sealing, or combinations of these methods.

The technology for combining these materials into a high performance composite is uncommon in the textile industry as a whole, but is commonly practiced by manufacturers specializing in high strength to weight ratio materials which see end uses in such applications as high performance sailcloth, insulation coverings for aircraft applications, and multilayer thermal protection systems for spacecraft applications.

TECHNICAL OBJECTIVES

The primary goal of the program was to test the theory that a composite material is a more versatile and effective method of providing the properties needed for low weight, tailored physical properties, and longer term product life than currently available coated fabric technology.

In order to accomplish this goal, three main technical objectives were proposed as follows:

1. Evaluate current materials and technology available for tent materials. Determine the key requirements of existing tent materials and identify those materials whose properties potentially most closely match these requirements either individually or in combination with other materials.

2. Obtain a variety of high performance films, fibers, adhesives, and coatings that when used in combination will potentially meet as many of the specification criteria proposed in MIL-C-44423(GL) for the Five Soldier Crew Tent as possible.

3. Fabricate and test samples of the above materials and propose a minimum of three composite (multilayer) constructions that demonstrate the closest match to the above FSCT Specifications. The current FSCT material was included in this objective for comparison purposes.

WORK PLAN

In order to accomplish the outlined objectives, the Work Plan for this Phase I contract consisted of five main tasks. Interim reports were submitted following each major task in the project.

TASK 1: LITERATURE SEARCH OF CURRENT TENT MATERIALS, TECHNOLOGIES, AND SOURCES

A literature search of products currently available and materials with desirable properties was performed using Dialog Information Retrieval Services. This included technical information on material properties, sources to obtain sample materials and identification of test facilities to perform specialized tests, as they were deemed necessary. The required test methods and MIL-STD specifications, were obtained.

A matrix was prepared analyzing the desirable criteria and properties of cost, weight, tensile strength, tearing strength, stiffness, and fire, water, weather and mildew resistance. Wherever possible, criteria specified in MIL-C-44423(GL), were obtained from either product or technical literature. Materials with the most desirable properties or those that potentially could contribute to successful composite constructions were selected for procurement.

TASK 2: PROCUREMENT OF SAMPLE MATERIALS

Materials selected from the literature search were procured in sufficient quantities for fabrication of several configurations and subsequent testing. Emphasis was placed on obtaining film and/or nonwoven substrates, reinforcing fibers, and potential protective or other property-enhancing coatings.

TASK 3: SAMPLE PREPARATION INTO COMPOSITE FORM

The initial approach involved selection of two substrate types, such as a continuous film and a nonwoven fabric. A fiber type and denier and an adhesive system were selected to provide additional reinforcement to the substrates for strength enhancement. Upwards of two protective coating systems were selected based on substrate and fiber type in order to provide flexibility and long term durability to the composite materials. It was anticipated that these combinations of materials would yield approximately ten composite samples, approximately one square yard each, for testing.

Since a wide variety of materials were identified and obtained for this program in TASKS 1 and 2 , the approach to fabrication of samples in TASK 3 was modified to include testing of some of the key properties identified in the specifications in order to more effectively determine classes of materials worthy of further study. Initial testing emphasized physical properties and flame resistance, with the idea that once acceptable composite constructions were identified, the work would concentrate on methods of enhancing other desired characteristics such as hand, color, and additional environmental durability.

TASK 4: TESTING

Prototype samples were tested for physical properties. Initial tests included weight , tensile breaking strength, tear strength, and flammability. Subsequent testing on composite systems exhibiting desirable results from the above tests were weatherability, stiffness, water resistance, and cold temperature flexibility.

Early in the TASK 3 fabrication work, it was determined that obtaining physical property and flammability test data on an ongoing basis was a more effective means of quickly identifying acceptable composite construction approaches. Consequently, a considerable amount of testing previously targeted for TASK 4 was performed in TASK 3. TASK 4 continued to develop new composite constructions as well as expand the scope of the testing to include more of the tests identified in the MIL-C-44423(GL) FSCT Specifications.

TASK 5: EVALUATION AND REPORTS

The test data for all sample materials constructed were analyzed and compared to the specification data identified in MIL-C-44423(GL). Material currently used in the FSCT walls was submitted to the same battery of tests for comparison purposes. The trade-offs of the reinforced composite approach to achieving the desired characteristics were evaluated and discussed. As noted earlier, interim reports were prepared at the completion of each of TASKS 1 through 4.

METHODS

A. SWATCH MAKING PROCEDURE

Orcon uses a patented process for producing reinforced continuous web goods which results in a series of warp yarns overlapped by adhesive-containing fill yarns which bond the warp and fill yarns at their crossover points and bond the warp yarns to the substrate. The advantages of the process are that no prefabricated scrim is required for the reinforcing portion of the composite, and no adhesive is required for the warp yarns since it is supplied by the fill yarn overlaps. The result is a very light, high strength reinforced film. The process is versatile in that it can accommodate a wide variety of substrate types and thicknesses, yarn types and deniers, and solvent, water-based, and 100 percent solids adhesive systems. The yarn count and type can be varied in both the warp and fill directions to provide for tailored physical properties in both the warp and fill directions. Continuous goods up to 58 inches in width can be produced.

Samples for the work in this program were produced on a laboratory scale system designed to simulate the production process as closely as possible. Sample swatches up to 32 inches x 32 inches are possible. While the laboratory scale system does not exhibit the precise yarn/inch registration routinely achieved on the large production machines, the physical property data for samples produced on the laboratory scale system have been shown to have good correlation with material produced on the standard production lines. The laboratory scale system is used as the starting point for all product development work within the Corporation.

B. TEST METHODS

As noted in various portions of the report, alternative test methods were substituted in some cases for several of the specialized tests such as flexibility identified in the FSCT MIL-C-4423 (GL) Specifications. Test methods have been identified in the results. Samples of the current FSCT sidewall material were run for all non-standard testing for comparison purposes. Properties such as gloss, mildew, and spectral reflectance characteristics could not be run due to unavailability of instrumentation. Product literature values for these properties were considered in the initial materials selection process. In addition, until the final composite geometries, coatings, and color characteristics can be added to the optimized candidates, the results of such testing were not considered to be relevant in the initial testing program.

RESULTS

TASK 1: LITERATURE SEARCH

The literature search was conducted using Dialog Information Retrieval Services with trade references and buyers guides. Twenty one types of commercially available materials were selected from the literature as being potential candidate materials for a composite tent fabric. These materials types were found to be available either as substrates, fibers, and/or coatings. The substrates are available as continuous films, woven fabrics, and/or nonwoven fabrics. The substrates primarily were chosen to provide strength, a surface for subsequent coating, and a water barrier. The fibers and the adhesives identified to adhere them to the substrates were chosen to provide additional strength to the composite constructions. Coatings can provide color, and flame and weather resistance and can potentially decrease stiffness.

Table 1 lists the material types and their configurations identified in the search as commercially available materials. In general, the desired properties required for the Five Soldier Crew Tent can be categorized into physical properties, environmental durability, hand and flexibility, and cost. Table 2 rates the Table 1 materials identified from the literature search to these relative characteristics through the general information contained in the literature.

TASK 2: SAMPLE PROCUREMENT

From the 21 types of materials identified in the literature search of TASK 1, suppliers, samples, technical literature, and Material Safety Data Sheets (MSDS) were sourced and selected for further study. Table 3 lists the obtained materials, their suppliers, and product names, available for the study. In all, 9 types of substrates, 6 types of reinforcing fibers or scrims, and 5 types of adhesives and/or coatings were obtained.

From the evaluation of the technical literature and MSDS information, an experimental approach was outlined for combining selected materials in the production and evaluation of composite samples. Some materials from Table 3 were excluded from the initial experimentation since they did not meet design criteria such as weight, compatibility, or no toxicity when used in combination with one another.

TASK 3 AND TASK 4: SAMPLE PREPARATION INTO COMPOSITE FORM AND TESTING

In all, a total of 44 different composite systems were fabricated. Material types used in the study included both woven and nonwoven polyester and fiberglass fabrics, polyester, urethane, polyethylene, polypropylene and polyvinyl fluoride films as substrates, polyester, polyaramid, and fiberglass yarns, and monofilament polyester fiber as reinforcement systems, and combinations of adhesives ranging from water-based, and solvent-based urethanes to 100 percent solids polyamide hot melt adhesives.

A total of 36 composite constructions were subjected to preliminary physical and flammability testing. Tables 4 through 7 detail the test results on these materials. From these results, 9 samples were selected on the basis of their performance in meeting desired characteristics for the FSCT and subjected to further testing as outlined in MIL-C-44423(GL). Samples of current FSCT side wall fabric provided by Natick were included in these results for comparison since not all of the test methods identified in the Specifications could be duplicated using our existing laboratory equipment. Table 8 summarizes the final results on these selected composite samples.

DISCUSSION

Of the materials identified through the literature search, the films listed in Table 3 obtained for the study covered a range of properties potentially satisfying various components of the desired characteristics.

At the low end of cost and weight are the oriented polypropylene (PP) films. Polypropylene exhibits good moisture and mildew resistance, but has poor long term weathering resistance. In addition, the film is flammable and is difficult to adhere to owing to its low surface energy. Consequently, should reinforced versions exhibit the necessary physical properties required, a polypropylene composite would require extensive modifications via coatings development to improve its flammability and weathering performance.

Intermediate in cost and weight are the polyester (PET) films, which exhibit good strength to weight properties as biaxially oriented films. PET exhibits good flammability characteristics in low gauge films owing to the tendency to shrink from the advancing flame front thus removing the fuel necessary to sustain combustion. They possess high surface energies and thus are readily adherable to a variety of adhesive systems. They exhibit good water and mildew resistance. They require protection in the form of coatings or additives for long term weathering protection, however, and do not have good "hand" properties, exhibiting increasing stiffness with increasing film thickness.

Urethane films are inherently superior to practically all others in terms of their flexibility and hand characteristics, being true elastomer systems. In this regard they are ideal candidates for producing highly flexible, low noise systems. However, they are generally flammable, and exhibit poor durability in outdoor weathering conditions. In addition, they are less desirable from a strength to weight ratio standpoint than polyesters, and more expensive on a per weight basis as well.

In principle, vinyl films (polyvinyl chloride or PVC) potentially match the flexibility performance characteristics of the urethanes at a significantly lower cost. However, most of their flexibility is due to plasticizer additions since the base polymer is inherently rigid and hence brittle in film form. Since the plasticizers are not generally incorporated into the backbone of the polymer, they are fugitive, and eventually migrate out of the film, particularly under outdoor weathering conditions, to leave a brittle, non-flexible substrate which is generally unacceptable as a long term tent material.

Fluorocarbon-containing films such as those marketed under the DuPont tradenames of Tedlar, and more recently Tefzel, offer high end performance in terms of their flammability, water, mildew, and overall weathering resistance. In particular, the polyvinyl fluoride film Tedlar has seen extensive use in the construction industry as an exterior siding material with excellent weathering characteristics. Since it sees use as an architectural product, it has been developed to accept a large variety of colors, conducive to matching the color requirements of the FSCT Specifications. Tedlar and other fluoropolymers, however, are heavier and significantly higher cost alternatives to polyesters for equivalent film thicknesses. Being in the "Teflon" family, they also exhibit low surface energies and thus present adhesion difficulties with most materials.

"Breathable" films, which can range from polyethylene (Exxaire), polypropylene (Celgard), to fluoropolymer materials (Gortex) on the surface appear to be interesting materials to allow expiration of moisture from tent interiors while preventing water ingress. Their performance, however, generally requires maintenance of a temperature differential on the order of 20 degrees F in order to maximize the transpiration of water vapor to the exterior surroundings. Such conditions may or may not always be available in the particular operating environment of the FSCT.

A number of choices exist for reinforcement fibers provided the requirements for high tenacity are met. Included in these are polyesters, polyamides (nylons), fiberglass, high strength polyethylene (Spectra), and polyaramid (Kevlar) fibers.

Continuous filament PET and Nylon yarns have seen widespread use as reinforcing systems and fabric structures in composite applications. They are available in a wide variety of deniers and physical properties. The majority of high performance thin film reinforcement is primarily composed of either polyester or nylon yarns. Of the two types, the polyesters are less moisture sensitive, and therefore more stable in their physical properties in environments where humidity is high or changes frequently. Typical equilibrium water contents of polyesters are on the order of 1 to 2 weight percent, while nylons can have upwards of 7 weight percent water in their structure. One of the detrimental consequences of the high water content of polyamides is that their physical properties can change depending on the amount of water present. High humidity, which translates to high water content, generally lowers the physical properties of nylons. The degree of change relative to their performance in tent structures, however, has not been demonstrated to have a negative effect on field performance.

Fiberglass yarns exhibit good tensile properties as well as being chemic`lly inert for the most part and generally impervious to the effects of weathering, even under severe environmental conditions. They are nonflammable, and have obviously seen extensive use as reinforcement systems in a wide variety of rigid composite applications. The Achilles Heel of fiberglass yarns for flexible composite reinforcement, however, is their poor transverse properties, and their relatively poor abrasion resistance. The crossover points between warp and fill yarns in a woven fabric, or in the reinforcement of films becomes a significant point of weakness in these systems after even moderate flexing due to the abrasion which takes place at fiber contact points. In addition, fabrication methods such as sewing can place transverse loads on the fibers and potential failure points at the material junctions of the tent, particularly under wind loading conditions.

One of the newer high tensile fibers entering the marketplace is an Allied Chemical polyethylene fiber with the tradename Spectra. Very highly oriented, the tensile properties of this yarn rival those of traditional high strength materials such as the polyaramids (Kevlar). The primary drawback to the use of this material as a reinforcement is the difficulty in adhering most commercially available adhesive systems to low surface energy polyethylenes.

As noted above, Kevlar polyaramid fibers are generally recognized as owning the high end of most commercially available tensilized yarns, both in tensile properties and unfortunately cost. They have seen extensive use in high performance rigid composites and as stand-alone fabrics. Their use in flexible composite structures has been limited, however. Kevlar exhibits poor transverse strength, and potentially can fibrillate upon flexing, particularly when the fibers are adhesively-bonded to a non-rigid substrate or embedded in a flexible matrix.

The primary characteristic of reinforcing fibers is their tensile properties. In a flexible composite system, more attention is required in identifying differences in transverse versus machine direction (direction of orientation) fiber physical properties. Because of the extensive flexure required in composite tent fabrics, fibers with more isotropic properties probably will exhibit better long term durability and reinforcing capacity than those possessing only high unidirectional strength.

In addition to fiber reinforcement, various nonwoven and lightweight woven fabric constructions also could provide strength to a flexible composite construction. An area of interest is the study of combinations of yarn and nonwoven fabric reinforcement in lightweight composites. Such a combination potentially allows for the use of lighter gauge continuous film substrates since the nonwoven may enhance resistance to puncture. Several polyester fabrics and nonwovens were obtained for this study. For this particular application, it would be envisioned that the reinforcing fibers, fabrics, or their combinations would either be exposed to the interior portions of the tent, and/or buried in a protective coating which would limit their exposure to water, mildew, or weathering conditions.

A wide variety of adhesive systems are available to bind reinforcing yarns to various substrates. However, in flexible composite systems, the requirements of flexibility, nonflammability, high adhesion, and moisture and weathering resistance limit the available options, particularly in consideration of environmental factors. Solvent based systems generally exhibit better adhesion characteristics but are less environmentally friendly. Water based systems satisfy most of the environmental requirements but in general do not offer the same performance characteristics as solvent based adhesives, particularly considering the humidity resistance required for this application. 100 percent solids systems, particularly hot melt adhesives, potentially offer the best balance of properties in a totally non-polluting system, provided they can retain their properties under the temperature extremes of the anticipated use environments.

The present study included a water-based urethane, a solvent-based urethane adhesive, a water-based acrylic, and a 100 percent solids polyamide hot melt adhesive. These were chosen on the basis of wishing to compare the performance of four different adhesive types of distinct compositions in the application, and on the basis that all exhibited either good substrate compatibility or the compliant property deemed necessary for sustaining the flexibility required of the final composite structure. Rigid adhesive systems were not included in the study for this reason.

Commercially available off the shelf coatings compositions for this application were difficult to obtain. Ideally, a coating should provide or improve flexibility or hand, provide UV protection for the film and reinforcing yarns, provide durability, abrasion and water resistance, be pigmentable to provide color variations, and at the same time provide or enhance nonflammability for the total flexible composite structure. It must perform these functions at reasonably low coating weights in order not to significantly add to the unit area weight of the composite. To the extent that a single coating composition might not meet all of these requirements, additions to the film component are necessary to make up for any shortcomings in the overall composite. Special coatings formulations generally are required to attempt to meet the stated requirements, and the Phase I work did not anticipate coatings formulation development. As a general class of coatings which seemed most applicable to meeting many of the requirements, particularly flexibility, abrasion, and durability improvements, urethane compositions were identified as the most likely candidates. Several commercially available urethane coatings were obtained in small quantities for feasibility studies.

The general experimental approach envisioned first the evaluation and optimization of reinforcing yarn materials while holding the substrates and adhesive systems constant. Once the most desirable reinforcing system was identified, the substrate was varied while holding the reinforcing material and adhesive system constant. Similarly, once the reinforcing system and preferred substrate were identified, they were held constant while the adhesive system was varied. These three steps were ideally designed to provide the optimum physical properties required of the composite. Additional properties which may be required at this stage of the study were to be provided through the addition of coatings to the flexible composites. The end of this process in principle would result in at least three candidates for further optimization and development.

In practice, this generalized approach proved to be too simplistic to account for additional variables which were identified as the work progressed. For example, the approach did not take into consideration the use of mixed yarn reinforcing systems such as polyester and Kevlar in order to enhance the characteristics of an all polyester system with the occasional interspersing of a higher tensile strength Kevlar yarn to improve tear characteristics. It also did not take into consideration an assessment of the effects of varying the yarn count on physical properties for a given yarn material. Similarly, the incorporation of more than one type of reinforcement, such as simultaneous use of a nonwoven fabric and yarn reinforcement was not initially considered. Lamination as a means of eliminating the need for coatings development also surfaced as a viable approach once the work was begun.

Consequently, early in the TASK 3 work it was determined that fabrication and limited testing of composite structures needed to take place simultaneously in order to effectively identify acceptable construction approaches. Using the test data as the basis for subsequent design work resulted in more work than anticipated, but also allowed for the exploration of a larger variety of constructions.

A total of 44 different constructions were evaluated during the course of the study. Tables 4, 5, 6, and 7 group the constructions by substrate type for the purposes of discussion.

A. POLYESTER SUBSTRATE CONSTRUCTIONS

Table 4 shows the results of the initial testing involving constructions using either 0.5 mil or 1.0 mil polyester film (DuPont Mylar) as a substrate. From our previous experience with reinforcing systems requiring high tensile strengths, a starting point of approximately 1000 denier polyester yarn was chosen for the initial work. Samples 4398 and 4423 illustrate the property variations resulting from increasing the yarn count from 6 x 6 to 8 x 8 yarns per inch in both the warp and fill directions using the same water-based urethane adhesive to bond the yarns to the polyester substrate. The unit weight in adding two 1100 denier PET yarns increases nearly 1 oz./sq. yd. from a 6x6 to 8x8 count. This is due to a combination of additional fiber and adhesive weight per unit area. The adhesive weight can be a significant variable in determining the overall sample unit area weight, even with the same yarn count. Adhesive weight differences depend on such factors as viscosity variations, distribution, and yarn coating weight. Note that the fill and warp tear values for both constructions do not vary significantly. Tensile warp and fill values, however, increase upwards of 40 lbs. in both directions owing to the additional yarn contributions.

Increasing the yarn count still further, to 10x10 yarns per inch and decreasing the film thickness to compensate for additional weight continues the same trend, with a progressive improvement in tensile strength, but no significant gains in tear properties, as illustrated in samples 4421 and 4436.

In terms of preliminary adhesive comparisons, from a physical properties standpoint the acrylic adhesive system exhibited relatively poor adhesion to PET, as indicated by the low tear values of Sample 4418. It also performed poorly in flammability tests, and further study with this system was discontinued early in the program. The water based urethane adhesive system showed good adhesion compatibility with PET, but also contributed to the poor flammability performance of constructions in which it was used, as evidenced in Samples 4398,4423,4399,and 4414. The solvent based urethane adhesive, and the polyamide hot melt adhesive exhibited good flammability performance, and adequate adhesion to PET as illustrated in Samples 4419, 4421, and 4436.

Overall polyester substrate thickness also had little effect on the physical properties of the composites, which indicates the prominent role played by the reinforcing yarns. From a flammability standpoint, since there is less fuel present for combustion, the thinner substrates would be favored. However, such properties as durability, water leakage, and puncture resistance become more significant factors with decreasing substrate thickness.

Samples 4399, and 4414 illustrate the effects of varying the yarn type or construction while maintaining a constant substrate and bonding adhesive. Compared with 4398, replacing the 1100 denier continuous filament PET yarn with either a 20 lb. test monofilament PET(Sample 4399), or an equivalent 6x6 continuous filament fiberglass yarn construction (Sample 4414) degrades tear strength performance. In the case of the monofilament PET, this degradation is attributed to the poorer distribution and contact area of bonding adhesive with the substrate relative to the continuous yarn PET. For the fiberglass construction, the degradation is attributed to the poor transverse properties (brittleness) of the yarn, as all tear samples exhibited yarn breakage in the tear region.

Sample 4437 was constructed entirely from 1000 denier Kevlar polyaramid fiber in both the warp and fill directions. As one might expect from such an ultra-high tensile strength fiber, the composite tensiles in both the warp and fill directions increased to nearly 300 lbs. Tear properties, however, were not significantly better than those exhibited by PET constructions.

Sample 4434 used a mixed yarn reinforcing system consisting of eight 1100 denier PET yarns followed by two 1000 denier Kevlar yarns per inch in both the warp and fill directions. The idea in this case would be to add a minimum amount of Kevlar to the system in order to achieve higher physical property performance at a lower cost compared to a completely Kevlar reinforced composite. The preliminary results indicated that not enough Kevlar was present to affect any measurable differences in physical properties. In addition, as shown in the Kevlar-containing Samples 4437 and 4434, the flammability characteristics of the composites were degraded in the presence of Kevlar. Kevlar, which is non-flammable, evidently prevents the polyester shrinkback from the advancing flame front thus allowing fuel to be present to support combustion. The flame front advanced between "corridors" of Kevlar in these flammability test samples.

Metallized films potentially could provide additional features in these constructions which could have advantages for this application. For example, the metallization could provide very lightweight opacity or EMI/RFI shielding characteristics with no loss in physical properties. Sample 4476 is a 10 x 8 count yarn reinforced 0.25 mil aluminized Mylar film. It meets all the minimum physical requirements but demonstrated poor flammability characteristics. Future coatings work with this system may improve flammability characteristics to the point where we could add the metallization feature to the composite construction.

B. FLUOROPOLYMER SUBSTRATE CONSTRUCTIONS

Table 5 shows the preliminary results of constructions using either 0.5 mil or 1.0 mil oriented polyvinyl fluoride film (DuPont Tedlar) as a substrate. Increasing the yarn count from 6x6 to 8x8 yarns per inch (Samples 4401,and 4424) produced results similar to the PET constructions, namely that warp and fill tears did not change appreciably, but tensiles increased on the order of 60 lbs. in both directions.

The same adhesive trends were also observed in comparing the PET and Tedlar substrates. The lower molecular weight water-based urethane adhesive performed poorly in flammability tests (Samples 4401, 4424, and 4400) compared to the higher molecular weight solvent-based urethane and the polyamide hot melt adhesives(Samples 4420,4440,and 4441). Both of these adhesives exhibited good substrate adhesion as evidenced in the warp and fill tear values for all continuous filament yarn samples. The monofilament PET reinforcement (Sample 4400) again exhibited low warp and fill tears as well as reduced tensile strength relative to the continuous filament yarn samples and lower flammability resistance.

The Kevlar-reinforced Sample 4439 also followed the PET substrate performance, in that relatively no change in tear properties was observed, tensile strength dramatically increased, and flammability resistance was poor. Interestingly enough, even though the fluoropolymer film should exhibit better flammability performance compared to polyester, as is the case with most halogenated systems, it appears that the Kevlar prevented shrinkback from the advancing flame front to an extent to which it was able to support combustion.

Sample 4441 was an identical construction compared to Sample 4440 with the exception that a thin, urethane-based, heat-sealable coating was applied to the yarn reinforcement side in anticipation of being able to fabricate seams using thermal sealing techniques. The presence of the coating did not appear to materially change any of the preliminary properties of the construction.

C. OTHER FILM SUBSTRATE CONSTRUCTIONS

Other substrates included in the study were selected primarily for their characteristics other than high physical properties. For example, two versions of a non-oriented cast Tedlar were examined in order to attempt to decrease the stiffness and/or reduce the "noise" characteristics of the final composite construction. Samples 4457 and 4458 were 10 x 8 1100 denier PET constructions of a clear and red pigmented 1.0 mil cast Tedlar. Overall physicals were satisfactory, even with the unoriented film since the yarn characteristics dominate the composite physical properties. However, both samples failed flammability due to the lack of orientation in the film and its subsequent ability to shrink from the flame front.

Samples 4449 and 4442 were 10 x 10 constructions using a 1.3 mil breathable polyethylene substrate from Exxon (Exxaire) which potentially could allow for moisture vapor transport from the interior to exterior of the FSCT. Sample 4449 failed flammability and showed marginal yarn adhesion. In Sample 4442, the substrate did not survive the temperature required to melt the hot melt adhesive and adhere the reinforcing yarns to the substrate.

Samples 4447 and 4450 were 10 x 10 1100 denier PET yarn constructions using a 1.2 mil biaxially oriented, multi-layer polypropylene packaging film (Bicor OPPalyte ASW from Mobil) with both a printable acrylic coating on one surface, which potentially would allow for a variety of colors and possibly camouflage patterns, and a heat sealable PVDC on the opposite surface for producing water tight seam seals. Both constructions, one using hot melt polyamide adhesive (4447) and one with solvent based urethane adhesive (4450), demonstrated good physical and flammability characteristics. Overall unit weight, however, for both constructions was slightly over the desired 5 oz. per sq. yd. maximum.

Two 1.0 mil urethane substrate composites were fabricated, one using the low molecular weight water based urethane adhesive and 8 x 8 PET yarn construction (4429), and one with the high molecular weight solvent-based urethane and a 10 x 10 PET yarn construction (4435). Sample 4429 failed flammability, as was the case with other samples using the low molecular weight water based urethane adhesive. Sample 4435 passed flammability and exhibited adequate physical as well as excellent softness and noiseless characteristics on flexing. Scrim adhesion, however, was marginal on this latter sample.

D. FABRIC AND NONWOVEN SUBSTRATE CONSTRUCTIONS

Several woven and non-woven constructions were fabricated to compare their overall physical properties to those of the continuous film substrates. Table 7 lists the results of these tests. Two polyester-based fabrics, a woven with a weight of 1.5 oz./sq.yd., and a nonwoven fabric with a weight of 1.07 oz./sq.yd. were laminated to both 1 mil PET and 1 mil Tedlar to investigate the need for yarn reinforcement. As shown in Samples 4407M, 4407T, 4408M, and 4408T, the tear and tensile properties for both of these systems were well below specifications, regardless of laminating film type. Heavier fabric and/or nonwoven systems, i.e., higher denier yarns or yarn counts could potentially improve the results, without exceeding the overall weight target, but were not available for this study.

Interestingly enough, these samples were laminated to the respective PET and PVF films using the same water based urethane adhesive system which contributed to the poor flammability characteristics of many of the early yarn reinforced systems as described previously. The fact that these non-reinforced constructions passed flammability testing could indicate that the high denier reinforcing yarns could play a role in increasing the

flammability in the earlier reinforced systems. Further work is required to isolate the flammability contributors in these systems.

Adding yarn reinforcement to the same woven PET fabric (Sample 4464A) or to the PET nonwoven (Sample 4451) dramatically increases the physicals of these materials compared to their unreinforced counterparts (Samples 4407T&M, 4408T&M) to values comparable to those exhibited by the continuous films. In this case it would appear that there is limited additional strength to weight benefit in the use of multiple layers of various reinforcing materials for this application, at least as indicated by the properties tested.

Sample 4459B represented a continuous filament fiberglass yarn fabric, reinforced with a 10x8 1100 denier PET yarn. Although the physical properties were adequate, the fabric prevented shrinkback of the yarn during combustion resulting in failure in the flammability testing.

Although not considered part of the scope of the Phase I work, several preliminary trials were made at "sandwiching" the reinforcing yarns between continuous films. Sample 4448A was an attempt at laminating a 0.5 mil Tedlar reinforced with a 10 x 10 1100 denier PET yarn to a 1 mil urethane or a PET nonwoven. Sample 4464B laminated a 0.5 mil Tedlar film onto Sample 4464A, described earlier. While both of these initial attempts did not exhibit satisfactory bonding, the concept of lamination merits further investigation in future work. Considerable trial and error effort is involved in achieving the correct level of laminating adhesive and laminating conditions (pressure, temperature, time, etc.) so it was not surprising that these preliminary trials were unsuccessful.

E. ADDITIONAL SAMPLES AND SPECIFICATION TESTING

Nine samples from the preliminary testing described previously were selected for further testing against the FSCT MIL-C-4423 (GL) Specifications. In this phase reasonable attempts were made to duplicate documented test procedures wherever possible, and substitute similar tests for methods in which test equipment was not available. In all cases, the currently used FSCT tent sidewall construction material was subjected to the same testing for comparison purposes.

Samples were selected from a variety of the constructions, primarily on the basis of substrate, since it was sufficiently demonstrated that the required strength properties could be achieved through continuous filament yarn reinforcement with a variety of adhesives. In some cases overweight samples were chosen on the basis of their uniqueness in offering property modifications or enhancements through the use of coatings.

Table 3 documents the results of the testing on these selected samples. The first observations are that the current FSCT material supplied to Orcon for testing by Natick does not meet several of the MIL-C-4423 (GL) Specifications. In particular, the current material is significantly below the breaking strength requirement. On the assumption that the test is representative of the stress

environment seen by the material for this application, the conclusion reached is that this could be a serious limitation in its performance. In addition, the vinyl coating on the supplied material showed significant degradation during weathering and subsequently could not pass the water permeability resistance test following weathering exposure.

With the exception of the "breathable" polyethylene film (Sample 4449) used in the study, which was low in tear strength and failed flammability , the majority of reinforced constructions listed generally meet or exceed the strength and flammability requirements for the application. The "Achilles Heel" for all samples tested is in their weathering characteristics. All samples, regardless of film type, exhibited degradation in an accelerated ageing environment. Furthermore, all samples failed the water permeability resistance test, indicating pinholes had developed in the films. In the initial tests, the continuous film samples all passed this test as well as the permeability following the cold crack test.

As discussed earlier in this report, we felt that the exceptional weathering characteristics demonstrated by Tedlar in outdoor use environments would be reflected in superior performance in the FSCT specification tests. While the Tedlar materials did exhibit the best overall weathering performance of any of the materials in this final phase of the study, they failed to meet the desired FSCT performance specifications. It is important to note, however, that the samples were prepared using clear, unpigmented Tedlar, which is seldom used for most outdoor applications, in particular as cladding for building siding. The application of a pigment, such as the green pigment added to the vinyl coating of the current FSCT fabric, is expected to significantly improve the weathering characteristics. In support of this assumption, red pigmented unreinforced Tedlar exposed to the identical conditions of our test samples showed no alteration in properties following accelerated ageing in the Weatherometer. This does not rule out the possibility that the yarn adhesive or the presence of the yarn/adhesive combination on the surface of the film did not contribute to the degradation. Further work is needed in this area before a clear conclusion can be reached.

The hand and noise characteristics of the continuous film constructions are also considered marginal at this time. Although we did not have the appropriate equipment for the Fed. Std. 5204 stiffness test, we did perform an alternate stiffness test (Fed. Std. 5200) including the current FSCT sidewall material for comparison. In all cases, the continuous film samples were "stiffer" and "noisier" in comparison to the current FSCT material. The addition of an elastomeric coating seems to improve flexibility as well as serve as a sound deadening system, as illustrated in Samples 4440*, 4464*, and 4476*. The most acceptable material from a flexibility and hand standpoint was the urethane film of Sample 4435. As pointed out earlier, however, poor weathering characteristics are inherent in these urethane systems.

As a further consideration, provided a protective coating is applied, the metallized Mylar film potentially could serve as a significant UV screen for underlying reinforcement structures as well as provide a means for achieving opacity at significant weight savings. Metallization may also offer other EMI/RFI shielding advantages which may be applicable in certain environments and circumstances. More investigative work is required in order to prove the feasibility of incorporating this additional feature into the composite construction.

CONCLUSIONS

The feasibility of developing light weight composite materials which exhibit high strength to weight ratios and significant versatility in providing tailored physical properties has been successfully demonstrated. These systems can be produced with commercially-available, reasonably low-cost materials. A variety of materials and constructions were shown to meet a majority of the requirements for the FSCT Tent Fabric Specifications.

However, none of the samples constructed during the study, including the current FSCT material supplied for comparison purposes, adequately demonstrated retention of properties following Weatherometer accelerated aging studies. As discussed in the report, the polyvinyl fluoride film composites expected to show excellent weathering resistance also exhibited degradation. Since a major portion of their use is in outdoor environments, we suspect that the fact that the reinforced materials used in this study were constructed from unpigmented film played a major role in these failures.

Future work on these light weight constructions should focus on the development of flexible coating systems to improve the hand and noise characteristics of the composites. The barrier property and weight advantages of continuous film composites are somewhat outweighed by their tendency towards less flexibility and higher noise levels compared to fabric substrates. However, to achieve low weight, coated fabrics require low denier yarns which degrade physical properties such as tear strength. Thus, development work should be continued on multiple layer systems which include the use of coatings, continuous films, fabrics and high strength reinforcement as composite laminates. By combining the best features of each of these materials, i.e., fabrics for flexibility and durability, fiber reinforcement for high strength, films and/or coatings for their barrier properties, color, spectral and weathering characteristics, the ultimate material for the FSCT application can be achieved.

TABLE 1

	MATERIAL TYPE	MATERIAL FORM		
		SUBSTRATE (NOTE 1)	FIBER	COATING
1	ACRYLIC	X	X	X
2	ALDEHYDES			X
3	BREATHABLE FILM	X		
4	COTTON	X	X	
5	ETFE	X		
6	EVA			X
7	FIBERGLASS	X	X	
8	KEVLAR	X	X	
9	NOMEX		X	
10	NYLON	X	X	
11	POLYESTER	X	X	X
12	POLYETHYLENE - LD	X		
13	POLYETHYLENE - HS		X	
14	POLYPROPYLENE	X		
15	POLY VINYL CHLORIDE			X
16	POLY VINYL FLOURIDE	X		
17	RUBBER BASED			X
18	SILICONE			X
19	URETHANE	X		X
20	VINYL	X		X
21	WOOL	X	X	

NOTE 1: *SUBSTRATE FORM COULD BE FILM OR FABRIC*

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TABLE 2

	PROPERTIES	PHYSICAL				ENVIRONMENTAL RESISTANCE			COST
	MATERIAL TYPE	STRENGTH TO WEIGHT	FLAMMA-BILITY	ADHESION	STIFFNESS	WEATHER	WATER	MILDEW	
1	ACRYLIC	+		0	-	+	+	+	+
2	ALDEHYDES			+		+			0
3	BREATHABLE FILM	0	+	0	+	+	-	+	-
4	COTTON	0	-	0	+	-	-	-	+
5	ETFE	0	+	0	0	+	+	+	-
6	EVA			+	+		+	+	+
7	FIBERGLASS	+	+	-	-	+	+	+	+
8	KEVLAR	+	+	0	-	-	0	+	-
9	NOMEX	+	+	0	0	0	+	+	-
10	NYLON	+	+	+	0	-	-	+	+
11	POLYESTER	+	+	+	0	-	+	+	+
12	POLYETHYLENE - LD	-	-	-	+	-	+	+	+
13	POLYETHYLENE - HS	+	0	-	+	-	+	+	-
14	POLYPROPYLENE	+	0	0	0	0	+	+	+
15	POLY VINYL CHLORIDE		+	+	+	+	+	+	+
16	POLY VINYL FLOURIDE	0	+	0	0	+	+	+	-
17	RUBBER BASED		+	+	0	0	0	0	+
18	SILICONE		+	0	+	+	+	+	-
19	URETHANE	-	0	+	+	+	0	+	0
20	VINYL	-	-	-	+	0	+	+	+
21	WOOL	0	+	0	+	+	+	0	+

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TABLE 3

SUBSTRATES		
MATERIAL TYPE	VENDOR	PRODUCT NAME
POLYESTER FILM	DUPONT ICI HOECHST-CELANESE	MYLAR MELINEX HOSTAPHAN
POLYETHYLENE FILM	EXXON	EXXAIRE
POLYPROPYLENE FILM	HOECHST-CELANESE MOBIL	CELGUARD OPPALYTE
POLYVINYL FLOURIDE FILM	DUPONT DUPONT	TEDLAR TEFZEL
URETHANE FILM	JP STEVENS FABINTE	
POLYARYLATE	CLEANESE	DUREL
NONWOVEN POLYESTER	REEMAY	TYPAR
NONWOVEN FIBERGLASS	ILLODALL	MANNING GLASS
POLYESTER AND NYLON FABRICS	STERN & STERN	

REINFORCING FIBERS AND SCRIM		
MATERIAL TYPE	VENDOR	PRODUCT NAME
NYLON FIBER	MONSANTO DUPONT DUPONT	NYLON 6 MULTIFILIMENT MONOFILIMENT
POLYESTER FIBER	DUPONT HOECHST-CELANESE	DACRON TREVIRA
ARAMID FIBER	DUPONT DUPONT	NOMEX KEVLAR
FIBERGLASS FIBER	PPG OWENS CORNING FIBERGLASS	
FIBERGLASS SCRIM	MILLIKEN	
POLYPHOPYLENE SCRIM	CONWEB	

ADHESIVES AND COATINGS		
MATERIAL TYPE	VENDOR	PRODUCT NAME
URETHANE	MORTON CHEMSECO SOLUOL	ADCOTE INCO, SMR SOLUCOTE
POLYAMIDE	BOSTIK	
SILICONE	SILITEX	
NEOPRENE	BURKE INDUSTRIES	
EVA	EXXON	

TABLE 4

POLYESTER SUBSTRATE CONSTRUC

PARAMETERS	METHOD	SPEC	ER 4398	ER 4423	ER 4421	ER 4438	ER 4418
FILM	-	-	1 mil Mylar	1 mil Mylar	0.5 mil Mylar	0.5 mil Mylar	1 mil Mylar
YARN	-	-	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron ECG 37 F.G.
COUNT	-	-	6x6	8x8	10x10	10x10	8x6
ADHESIVE	-	-	OA-65	OA-65	Adcote 122	87239	Joncryl
WEIGHT oz./sq.yd.	FTMS-191A Met. 5041	≤5.0	3.5	4.5	4.3	5.1	3.6
BURST psi	FTMS-191A Met. 5122	-	191	-	195	-	150
TEARING STRENGTH WARP lbs. FILL	FTMS-191 Met. 5134	≥5.5 ≥5.5	17.3 14.4	22.3 20.5	8.7 8.2	12.1 16.5	3.2 3.1
BREAKING STRENGTH TENSILE WARP lbs./inch FILL	DAN-451	≥175 ≥150	113.3 131.7	175.1 171.3	185.0 191.3	208.7 213.3	186.0 82.7
…C. VERT. BURN …AR LENGTH WARP inch FILL	FTMS-191A Met. 5903	≤6.0 -	- -	- -	- -	- -	- -
BURN LENGTH inch WARP FILL		- -	7 10 5 8 7 5	5.5 4 6.5 6.5	3.8 2.8 1.5 2.8 3 2	0.5 0.5 0 0 0 0	13 13 13 11 10.8 11.5
EXT. TIME WARP sec. FILL		≤2.0 -	8 15 0 9 6 0	7 9 6 21	0 0 0 0 0 0	0 0 0 0 0 0	26 27 38 36 16 14
DRIP EXT. TIME WARP sec. FILL		No dripping -	4 7 0 3 2 0	0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	8 7 8 0 0 0

TABLE 4

STER SUBSTRATE CONSTRUCTIONS

ER 4421	ER 4436	ER 4418	ER 4419	ER 4399	ER 4414	ER 4437	ER 4434	ER 4476
0.5 mil Mylar	0.5 mil Mylar	1 mil Mylar	1 mil Mylar	1 mil Mylar	1 mil Mylar	0.5 mil Mylar	0.5 mil Mylar	0.25 mil met. Mylar
1100d Dacron	1100d Dacron	1100d Dacron ECG 37 F.G.	1100d Dacron	20 lb. Monof.	ECG 37 2x ECG 75 F.G.	1000d Kevlar	1100d Dacron 1000d Kevlar	1100d Dacron
10x10	10x10	8x6	8x8	6x6	6x6	10x10	8+2x8+2	10x8
Adcote 122	B7239	Joncryl	Adcote 122	OA-65	OA-65	Adcote 122	Adcote 122	B7239
4.3	5.1	3.6	3.9	4.2	3.4	4.1	4.2	4.6
195	-	150	-	162	200	-	-	-
8.7 8.2	12.1 16.5	3.2 3.1	10.5 5.8	7.4 8.6	5.7 12.3	10.4 6.0	5.5 9.7	7.8 10.9
185.0 191.3	208.7 213.3	186.0 82.7	159.8 142.3	132.3 125.0	122.0 151.0	283.5 294.5	171.3 147.7	180.3 177.0
- -	- -	- -	- -	- -	- -	- -	- -	5.0 5.2 5.0 6.0 5.2 4.5
3.8 2.8 1.5 2.8 3 2	0.5 0.5 0 0 0 0	13 13 13 11 10.8 11.5	2 0.25 3 2	3.5 3.5 3 4 4.5 3	13 13 13 13 13 13	13 13 13 13 13 13	13 13 13 13 13 13	- -
0 0 0 0 0 0	0 0 0 0 0 0	26 27 38 36 16 14	0 0 0 0	0 12 0 22 25 0	2 3 5 2 2 4	23 20 52 58 29	25 31 38 63 42 64	9 0 0 11 11 4
0 0 0 0 0 0	0 0 0 0 0 0	8 7 8 0 0 0	0 0 0 0	0 4 0 6 7 0	0 0 0 0 0 0	0 3 - 20 48 13	0 1 7 20 12 3	0 1 0 3 2 1

TABLE 5

FLUOROPOLYMER SUBSTRATE CONSTRUCTIO

PARAMETERS	METHOD	SPEC	ER 4401	ER 4424	ER 4420	ER 4462	EF
FILM	-	-	1 mil Tedlar	1 mil Tedlar	1 mil Tedlar	1 mil Tedlar	cle
YARN	-	-	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	D
COUNT	-	-	6x6	8x8	8x8	10x8	
ADHESIVE	-	-	OA-65	OA-65	Adcote 122	B7239	
WEIGHT oz./sq.yd.	FTMS-191A Met. 5041	≤5.0	3.6	4.6	4.0	5.3	
THREAD ADHESION lbs./1.5 inch	BMS 8-142R	-	-	-	-	6.9	
BURST psi	FTMS-191A Met. 5122	-	180	-	-	-	
TEARING STRENGTH lbs. WARP FILL	FTMS-191 Met. 5134	≥5.5 ≥5.5	38.7 19.3	41.6 25.8	18.1 7.5	14.8 14.5	
BREAKING STRENGTH TENSILE lbs./inch WARP FILL	DAN-451	≥175 ≥150	111.3 116.7	170.9 162.6	135.3 144.1	176.7 179.3	
BREAKING STRENGTH GRAB lbs./inch WARP FILL	FTMS-191A Met. 5100	≥175 ≥150	- -	- -	- -	192.5 168.0	
12 SEC. VERTICAL BURN	FTMS-191A Met. 5903						
CHAR LENGTH inch WARP FILL		≤6.0 -	- -	- -	- -	0 0.5 1.0 1.0 1.2 0.5	3.5 4.0
BURN LENGTH inch WARP FILL		- -	4 3.5 7 3 3 4	3 3.5 5 5	2 1 0.5 1	- -	0
EXT. TIME sec. WARP FILL		≤2.0 -	3 7 30 0 0 0	3 6 12 17	0 0 0 0	0 0 0 0 0 0	
DRIP EXT. TIME sec. WARP FILL		No dripping -	1 3 8 0 0 0	0 0 0 0	0 0 0 0	- -	

TABLE 5

ION -UOROPOLYMER SUBSTRATE CONSTRUCTIONS

C	ER 4401	ER 4424	ER 4420	ER 4462	ER 4440	ER 444[illegible]	ER 4400	ER 4439
ER 4 0.5 clear	1 mil Tedlar	1 mil Tedlar	1 mil Tedlar	1 mil Tedlar	0.5 mil clear Tedlar	0.5 mil coat. Tedlar	1 mil Tedlar	0.5 mil clear Tedlar
11 Dac	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	20 lb. Monof.	1000d Kevlar
8	6x6	8x8	8x8	10x8	8x8	8x8	6x6	8x8
B7.	OA-65	OA-65	Adcote 122	B7239	B7239	B7239	OA-65	B7239
0 4	3.6	4.6	4.0	5.3	4.4	4.6	4.4	3.9
8	-	-	-	6.9	8.7	-	-	-
	180	-	-	-	-	-	113	-
5 1[illegible]5 1[illegible]	38.7 19.3	41.6 25.8	18.1 7.5	14.8 14.5	18.6 14.5	19.8 17.1	11.7 9.0	22.2 20.7
'5 14[illegible]0 16	111.3 116.7	170.9 162.6	135.3 144.1	176.7 179.3	143.9 163.7	148.0 155.0	107.2 83.3	297.3 324.3
'5 15[illegible]0 17	- -	- -	- -	192.5 168.0	151.0 174.5	- -	- -	- -
0 3.5 3 4.0 4	- -	- -	- -	0 0.5 1.0 1.0 1.2 0.5	3.5 3.8 3.9 4.0 4.2 3.0	- -	- -	- -
0 0 0	4 3.5 7 3 3 4	3 3.5 5 5	2 1 0.5 1	- -	0 1 0 0 0 0.5	0 0 0 0.8 0 0	2 2.5 3 6 4.5 3	13 13 13 13 13 13
0 0 0	3 7 30 0 0 0	3 6 12 17	0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 7 10 0	24 24 27 24 31 22
ping 0 0	1 3 8 0 0 0	0 0 0 0	0 0 0 0	- -	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 4 0	5 3 7 9 4 6

TABLE 6

OTHER CONTINUOUS FILM SUBSTRATE CONSTI

PARAMETERS	METHOD	SPEC	ER 4457	ER 4458	ER 4449	ER 4442	E
FILM	-	-	1.0 mil Tedlar (cast red)	1.0 mil Tedlar (cast clear)	1.3 mil breathable Polyethylene	1.3 mil breathable Polyethylene	Poi
YARN	-	-	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	11(
COUNT	-	-	10x8	10x8	10x10	10x10	
ADHESIVE	-	-	B7239	B7239	Adcote 122	B7239	
WEIGHT oz./sq.yd.	FTMS-191A Met. 5041	≤5.0	5.3	5.1	4.5	Film melted at 230°F	
THREAD ADHESION lbs./1.5 inch	BMS 8-142R	-	5.9	6.2	1.0	-	
BURST psi	FTMS-191A Met. 5122	-	-	-	-	-	
TEARING STRENGTH lbs. WARP FILL	FTMS-191 Met. 5134	≥5.5 ≥5.5	24.4 17.4	16.3 17.2	4.5 6.0	- -	
BREAKING STRENGTH TENSILE lbs./inch WARP FILL	DAN-451	≥175 ≥150	168.7 156.0	195.3 144.5	172.0 194.0	- -	
BREAKING STRENGTH GRAB lbs./inch WARP FILL	FTMS-191 Met. 5100	≥175 ≥150	183.C 200.0	184.0 200.0	156.0 169.5	- -	
12 SEC. VERTICAL BURN	FTMS-191A Met. 5903						
CHAR LENGTH inch WARP FILL		≤6.0 -	5.3 6.3 7.5 4.5 6.0 5.0	4.5 3.2 3.0 2.8 3.2 3.5	4.5 5.5 13 5.0 6.5 4.0	- -	2. 3.
BURN LENGTH inch WARP FILL		- -	- -	- -	3.0 4.0 13.0 5.0 6 5 3.5	- -	(0.
EXT. TIME sec. WARP FILL		≤2.0 -	17 15 15 15 12 18	24 0 0 0 0 1	4 0 91 30 37 0	- -	
DRIP EXT. TIME sec. WARP FILL		No dripping -	- -	- -	0 0 45 0 0 0	- -	

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TABLE 6

)NTINUOUS FILM SUBSTRATE CONSTRUCTIONS

…4457	ER 4458	ER 4449	ER 4442	ER 4447	ER 4450	ER 4429	ER 4435
…) mil …dlar …t red)	1.0 mil Tedlar (cast clear)	1.3 mil breathable Polyethylene	1.3 mil breathable Polyethylene	MOBIL Polypropylene	MOBIL Polypropylene	1.0 mil Urethane	1.0 mil Urethane
…00d …cron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron
…)x8	10x8	10x10	10x10	10x10	10x10	8x8	10x10
…239	B7239	Adcote 122	B7239	B7239	Adcote 122	OA-65	Adcote 122
…).3	5.1	4.5	Film melted at 230°F	5.9	5.1	4.2	4.6
….9	6.2	1.0	-	2.6	-	-	1.0
-	-	-	-	-	-	121	-
4.4 7.4	16.3 17.2	4.5 6.0	- -	26.2 16.3	21.0 8.4	22.5 24.2	6.0 5.2
…38.7 …56.0	195.3 144.5	172.0 194.0	- -	194.8 191.7	226.3 213.3	152.7 157.3	181.7 187.3
…33.0 …00.0	184.0 200.0	156.0 169.5	- -	200.0 229.0	- -	- -	168.0 191.5
6 3 7.5 6.0 5.0	4.5 3.2 3.0 2.8 3.2 3.5	4.5 5.5 13 5.0 6.5 4.0	- -	2.0 2.5 3.0 3.0 3.0 3.0	- -	- -	4.0 3.0 4.2 3.5 3.2 3.5
- -	- -	3.0 4.0 13.0 5.0 6.5 3.5	- -	0 0 1.5 0.5 0.5 1.5	1 0.5 1.5 4.5 2 3	10.5 9 3.5 6.5 7.5 4 4 3.5 4 3.8	3.0 2.0 3.0 2.0 2.5 3.5
15 15 12 18	24 0 0 0 0 1	4 0 91 30 37 0	- -	0 0 0 0 0 0	0 0 0 26 0 0	59 27 3 0 9 0 0 0 0 0	0 0 0 0 0 0
- -	- -	0 0 45 0 0 0	- -	0 0 0 0 0 0	0 0 0 20 0 0	4 4 3 3 4 2 2 1 2 1	0 0 0 0 0 0

TABLE 7

FABRIC AND NONWOVEN SUBSTRATE CONSTR

?AMETERS	METHOD	SPEC	ER 4459	ER 4464A,B	ER 4467A,B	ER 4451	ER 4407
?LM	-	-	Glass cloth (for FB-28)	Woven Polyester	Light Woven Polyester	Nonwoven Polyester	1 mil Myl
YARN	-	-	1100d Dacron	1100d Dacron	1100d Dacron	1100d Dacron	-
COUNT	-	-	10x8	10x8	10x8	10x10	-
ADHESIVE	-	-	B7239	B7239	B7239	B7239	OA-6
FABRIC	-	-	-	-	-	-	Woven Poly
WEIGHT OF FILM oz./sq.yd.	-	-	1.4	1.5	0.9	1.1	-
WEIGHT OF FABRIC oz./sq.yd.	-	-	-	-	-	-	1.5
WEIGHT oz./sq.yd.	FTMS-191A Met. 5041	≤5.0	5.7	5.8	5.2	5.8	3.2
THREAD ADHESION lbs./1.5 inch	BMS 8-142R	-	5.5	6.6	8.9	-	-
BURST psi	FTMS 191A Met. 5122	-	-	-	-	-	200
TEARING STRENGTH WARP lbs. FILL	FTMS-191 Met. 5134	≥5.5 ≥5.5	21.8 18.7	38.9 21.9	20.9 16.6	32.0 17.1	2.8 3.3
BREAKING STRENGTH TENSILE WARP lbs./inch FILL	DAN-451	≥175 ≥150	185.3 169.7	211.7 191.0	200.3 186.7	215.2 216.3	84. 84.
BREAKING STRENGTH GRAB WARP l? ?ch FILL	FTMS-191A Met. 5100	≥175 ≥150	200.0 182.5	233.0 191.0	217.5 186.5	- -	- -
?. VERTICAL BURN	FTMS-191A Met. 5903						
CHAR LENGTH WARP inch FILL		≤6.0 -	13 13 13 13 13 13	2.0 3.5 3.0 3.0 3.5 2.0	3.0 3.5 3.0 4.0 4.0 4.0 3.5	- -	- -
BURN LENGTH WARP inch FILL		- -	- -	- -	- -	0 0 0 1 0.5 1	5.5 3.5 0 1.0
EXT. TIME WARP sec. FILL		≤2.0 -	34 41 32 41 57 111	0 0 0 0 0 0	0 0 0 3 0 0 0	0 0 0 0 0 0	0 0 0 0
DRIP EXT. TIME WARP sec. FILL		No dripping -	- -	0 0 0 1 0 0	- -	0 0 0 0 0 0	0 0 0 0

*Lamination: Film + woven/nonwoven.

ER 4448A Laminated with 1 mil Urethane film (300°F, 10 tons, 20 seconds) - *uneven aspect.*
Same lamination using rubber pad on Urethane side - *uniform aspect.*
Laminated with Nonwoven Polyester - *uniform aspect.*
Coated with Adcote 122 (weight 6.3 oz./sq. yd., 7.05 oz./sq. yd.) - *sticky.*

ER 4464B Laminate
Coated v
Coated v

ER 4467B Coated v

TABLE 7

…ND NONWOVEN SUBSTRATE CONSTRUCTIONS

…RUC	…4464A,B	ER 4467A,B	ER 4451	ER 4407M*	ER 4407T*	ER 4408M*	ER 4408T*	ER 4448A
…7M*	…ven Polyester	Light Woven Polyester	Nonwoven Polyester	1 mil Mylar	1 mil Tedlar	1 mil Mylar	1 mil Tedlar	0.5 mil clear Tedlar
…ylar	…0d Dacron	1100d Dacron	1100d Dacron	-	-	-	-	1100d Dacron
	10x8	10x8	10x10	-	-	-	-	10x10
	B7239	B7239	B7239	OA-65	OA-65	OA-65	OA-65	B7239
	-	-	-	Woven Polyester	Woven Polyester	Nonwoven Polyester	Nonwoven Polye…ter	-
…65 …yester	1.5	0.9	1.1	-	-	-	-	0.5
	-	-	-	1.5	1.5	1.1	1.1	-
	5.8	5.2	5.8	3.2	3.3	2.7	2.8	5.2
…5 …2	6.6	8.9	-	-	-	-	-	-
	-	-	-	200	170	97	74	-
…0	38.9 21.9	20.9 16.6	32.0 17.1	2.8 3.3	2.2 1.9	1.7 2.0	2.1 1.7	- -
…8 …3	211.7 191.0	200.3 186.7	215.2 216.3	84.5 84.5	65.7 60.5	38.3 45.2	21.6 25.2	- -
.5 .5	233.0 191.0	217.5 186.5	- -	- -	- -	- -	- -	- -
	… 3.5 3.0 … 3.5 2.0	3.0 3.5 3.0 4.0 4.0 4.0 3.5	- -	- -	- -	- -	- -	- -
	- -	- -	0 0 0 1 0.5 1	5.5 3.5 5.5 0 1.0 1.5	0.5 0.5 1.0 0.5 0.5 0.5	1.5 1.0 1.0 1.0 1.5 1.5	0 0 0.5 0.5 0.5 0.5	- -
.5 5.5 … 1.5	0 0 0 0 0 0	0 0 0 3 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	- -
… 0 … 0	0 0 0 1 0 0	- -	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	- -
… 0 … 0								

…, 20 seconds) - *uneven aspect*.
… *uniform aspect*.
…ted w…t.
with …5 oz./sq. yd.) - *sticky*.
with
with

ER 4464B — Laminated with 0.5 mil clear Tedlar.
Coated with SMR 1618FR, black, straight, weight 8.6 oz./sq. yd.
Coated with SMR 1618FR, black + CAB-O-SIL, weight 9.69 oz./sq. yd.

ER 4467B — Coated with SMR 1618FR, black, straight, weight 6.51 oz./sq. yd.

TABLE 8

SPECIFICATION TESTING OF SELECTED COMPOSITE CONSTI

PARAMETERS		METHOD	SPEC	FSCT-MATL	ER 4435	ER 4440	ER 4440*	ER 4447	
.M		-	-	-	1.0 mil Urethane	0.5 mil clear Tedlar	0.5 mil clear Tedlar	Mobil Polypropylene	1.
COUNT		-	-	-	10x10	8x8	8x8	10x10	
ADHESIVE		-	-	-	Adcote 122	B7239	B7239	B7239	
WEIGHT	oz./sq.yd.	FTMS-191A Met. 5041	≤5.0	4.7	4.6	4.4	7.8	5.9	
THREAD ADHESION	lbs./1.5 inch	BMS 8-142R	-	-	1.0	8.7	-	2.6	
TEARING STRENGTH lbs.	WARP FILL	FTMS-191 Met. 5134	≥5.5 ≥5.5	12.0 10.2	6.0 5.2	18.6 14.5	- -	26.2 16.3	
BREAKING STRENGTH TENSILE lbs./inch	 WARP FILL	DAN-451	≥175 ≥150	114.7 101.7	181 7 187.3	143.9 163.7	- -	194.8 191.7	
BREAKING STRENGTH GRAB lbs./inch	 WARP FILL	FTMS-191A Met. 5100	≥175 ≥150	165.5 165.0	168.0 191.5	151.0 174.5	- -	200.0 229.0	
BREAKING STRENGTH GRAB lbs./inch	 WARP FILL	ASTM D 5034-90	≥175 ≥150	68.7 53.5	215.0 197.5	138.5 168.0	- -	193.5 216.0	
12 SEC. VERTICAL BURN		FTMS-191A Met. 5903							
CHAR LENGTH inch	WARP FILL		≤6.0 -	3.5 3.5 3.2 4.5 4.5 3.8	4.0 3.0 4.2 3.5 3.2 3.6	3.5 3.8 3.9 4.0 4.2 3.0	- -	2.0 2.5 3.0 3.0 3.0 3.0	
EXT. TIME sec.	WARP FILL		≤2.0 -	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	- -	0 0 0 0 0 0	
DRIP EXT. TIME sec.	WARP FILL		No dripping -	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	- -	0 0 0 0 0 0	
BLOCKING		FTMS-191A Met. 5872	Scale 2	1	2	2	2	4	
Resistance to weathering ?°C, 8 hours °C, 4 hours otal time: 436.8 hours, Light time: 305.3 hours	 U.V. Condensing		No change	Coating effected Abraded very easily	Film Brittle, Yellow	Film Split	Film Split	Film Totally Degraded	
Resistance to Cold Cracking -40°F, 2 Hours		FTMS-191A Met. 5874 3/	No crack	Pass	Pass	Pass	Pass	Pass	
Water Permeability • Initial • After Weathering • After Cold Crack			 No leakage No leakage No leakage	 Pass Fail Pass	 Pass Fail Pass	 Pass Fail Pass	 Pass Fail Pass	 Pass Fail Pass	
STIFFNESS - centimeters • Initial Face outside loop Face inside loop • AT -20°F Face outside loop	 WARP FILL WARP FILL WARP	FTMS-191A 5200		 6.51 6.67 6.35 7.62 5.30	 4.76 4.92 4.60 5.56 5.00	 5.40 5.72 4.22 3.97 4.70	 4.45 5.08 3.81 4.60 4.10	 7.14 4.60 4.76 4.13 8.40	

YARN - 1100d Dacron
*Coated on yarn side with SMR 1618FR, black

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TABLE 8

ON TESTING OF SELECTED COMPOSITE CONSTRUCTION

R 4435	ER 4440	ER 4440*	ER 4447	ER 4449	ER 4464	ER 4464*	ER 4476	ER 4476*
1.0 mil Urethane	0.5 mil clear Tedlar	0.5 mil clear Tedlar	Mobil Polypropylene	1.3 mil breathable Polyst.	Woven Polyester	Woven Polyester	0.25 mil met. Mylar	0.25 mil met. Mylar
10x10	8x8	8x8	10x10	10x10	10x8	10x8	10x8	10x8
Adcote 122	B7239	B7239	B7239	Adcote 122	B7239	B7239	B7239	B7239
4.6	4.4	7.8	5.9	4.5	5.8	9.7	4.6	7.8
1.0	8.7	-	2.6	1.0	6.6	-	1.3	-
6.0 5.2	18.6 14.5	- -	26.2 16.3	4.5 6.0	38.9 21.9	- -	7.8 10.9	- -
181.7 187.3	143.9 163.7	- -	194.8 191.7	172.0 194.0	211.7 191.0	- -	180.3 177.0	- -
168.0 191.5	151.0 174.5	- -	200.0 229.0	156.0 169.5	233.0 191.0	- -	195.0 197.5	- -
215.0 197.5	138.5 168.0	- -	193.5 216.0	170.0 176.0	200.0 190.0	- -	198.5 177.0	
0 3.0 4.2 5 3.2 3.5	3.5 3.8 3.9 4.0 4.2 3.0	- -	2.0 2.5 3.0 3.0 3.0 3.0	4.5 5.5 13 5.0 6.5 4.0	2.0 3.5 3.0 3.0 3.5 2.0	- -	5.0 5.2 5.0 6.0 5.2 4.5	3.8 4.8 5.0
0 0 0 0 0 0	0 0 0 0 0 0	- -	0 0 0 0 0 0	4 0 81 30 37 0	0 0 0 0 0 0	- -	9 0 0 11 11 4	4 0 16
0 0 0 0 0 0	0 0 0 0 0 0	- -	0 0 0 0 0 0	0 0 45 0 0 0	0 0 0 1 0 0	- -	0 1 0 3 2 1	0 0 0
2	2	2	4	2	1.5	2	2	2
m Brittle, Yellow	Film Split	Film Split	Film Totally Degraded	Film Totally Degraded	Discolored Yellow	Discolored Yellow	Film Damaged	Film Damaged
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass Fail Pass	Pass Fail Pass	Pass Fail Pass	Pass Fail Pass	Pass Fail Pass	Fail Fail Fail	Fail Fail Fail	Pass Fail Fail	Pass Fail Pass
4.76 4.92 4.60 5.56	5.40 5.72 4.22 3.97	4.45 5.08 3.81 4.60	7.14 4.60 4.76 4.13	5.08 4.76 5.08 4.92	6.83 5.24 5.87 4.29	5.40 4.76 4.92 3.97	5.72 4.13 5.24 4.92	4.76 4.76 4.60 4.45
5.00	4.70	4.10	8.40	4.00	5.10	4.60	4.70	3.50